TITLE OF THE INVENTION

AUTOMATIC GAIN CONTROL APPARATUS

BACKGROUND OF THE INVENTION

5   Field of the Invention

[0001]   The present invention relates to apparatuses for
receiving television and radio broadcasting, especially digital
broadcasting.

10   Description of the Background Art

[0002]   Shown in FIG. 14 is the structure of an automatic gain
control apparatus (hereinafter referred to as AGC apparatus)
conventionally used for a digital broadcast receiving apparatus.
The AGC apparatus AGC includes a tuner 30, an A/D converter 6,
15   a level detector LD, and an automatic gain control signal
generator (hereinafter, AGC signal generator) SG. The tuner 30
includes an RF automatic gain controller 2 for controlling the
gain of a digital broadcast wave RF, a mixer 3, an oscillator 4,
an IF automatic gain controller 5 for controlling the gain of an
20   intermediate frequency signal Sif , and an RF gain control point
setter 40.

[0003]   In the tuner 30, the RF automatic gain controller 2
carries out automatic gain control and amplification of the
digital broadcast wave RF for generating a digital broadcast wave
25   Srf. This amplification is carried out based on an RF automatic

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gain control signal (hereinafter, RF AGC signal) *SAGr* supplied by the RF gain control point setter 40. The mixer 3 frequency-converts the digital broadcast wave *Srf* for generating the intermediate frequency signal *Sif*. This frequency conversion is carried out based on a reference frequency signal *SB* supplied by the oscillator 4. The IF automatic gain controller 5 carries out automatic gain control and amplification of the intermediate frequency signal (hereinafter, IF signal) *Sif* for generating an modulated analog signal *SMA*. In short, the tuner 30 generates the modulated analog signal *SMA* by frequency-converting and amplifying the digital broadcast wave *RF* received via an antenna.

[0004] The A/D converter 6 converts the modulated analog signal *SMA* from analog to digital for generating a modulated digital signal *SMD*. The modulated digital signal *SMD* is outputted to the following demodulation processing and also to the level detector *LD*.

[0005] The level detector *LD* detects the average level of the modulated digital signal *SMD*, and generates a level signal *SL*. The level signal *SL* indicates the level of the output from the IF automatic gain controller 5, that is, the level of the modulated analog signal *SMA*.

[0006] The AGC signal generator *SG* generates an automatic gain control signal (hereinafter, AGC signal) *SAG* based on the level signal *SL*. The AGC signal *SAG* is a control signal for controlling

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the gain of the RF automatic gain controller 2 and the IF automatic gain controller 5.

[0007] The RF gain control point setter 40 generates, based on the AGC signal SAG, an IF automatic gain control signal (hereinafter, IF AGC signal) *SAGi* for controlling the IF automatic gain controller 5 and an RF automatic gain control signal (hereinafter, RF AGC signal) *SAGr* for controlling the RF automatic gain controller 2.

[0008] Shown in FIG. 15 is the structure of the level detector *LD* in detail. The level detector *LD* includes a subtractor 12, an adder 13, a delay unit 14, and a bit shifter 15 (represented as "2^{-n}" in FIG. 15). Note that n represents the number of shift bits. The adder 13 and the delay unit 14 form an integrator 100. For example, if an average value is obtained from $128 = 2^7$ values of data, n is set to 7. If obtained from $2048 = 2^{12}$ data values, n is set to 12.

[0009] The digital modulated signal *SMD* coming from the A/D converter 6 goes to the subtractor 12, where an averaged signal $Y/2^n$ received from the bit shifter 15 is subtracted from the modulated digital signal *SMD*. Then, the subtraction result is outputted to the integrator 100.

[0010] Shown in FIG. 16 is the structure of the AGC signal generator *SG* in detail. The AGC signal generator *SG* includes a subtractor 16, a reference value provider 17, a multiplier 18, a constant provider 19, an integrator 22, a level converter *LC*,

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a PWM (Pulse Width Modulator) 42, and a low-pass filter 43. The integrator 22 includes an adder 20 and a delay unit 21. The level converter LC includes a multiplier 23, an inverse coefficient provider 24, an adder 38, and a compensation coefficient provider 39.

[0011]   The subtractor 16 finds an error between the level signal SL supplied by the level detector LD and a predetermined reference value R supplied by the reference value provider 16, and generates an error signal SE. Note that, for the purpose of simplifying the description, signals and parameters may hereinafter be simply represented by reference characters as required. The multiplier 18 multiplies the error signal SE received from the subtractor 16 by a constant G received from the constant provider 19 to generate $G \cdot SE$ for output to the integrator 22.

[0012]   In the integrator 22, the delay unit 21 first delays $G \cdot SE$ outputted from the multiplier 18 by a control cycle t, and then the adder 19 adds the delayed signal to a current output from the multiplier 18 for integration of $G \cdot SE$. The integration result is outputted as an integrated signal Z from the delay unit 21 to the adder 20 and the level converter LC. Note herein that one control cycle is a sequence of control processing successively carried out in the conventional automatic gain controller or the automatic gain controller according to the present invention, and their components. Also note that one control cycle period is a

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time period required for execution of one control cycle, that is, a period from start of one control cycle until before start of the next control cycle.

[0013]   In the level converter LC, the multiplier 23 multiplies the integrated signal Z outputted from the integrator 22 by "-1" outputted from the inverse coefficient provider 24 to invert the polarity of the integrated signal Z, and generates $-Z$. The adder 38 adds a compensation coefficient OB provided by the compensation coefficient provider 39 to $-Z$ provided by the multiplier 23, and generates $-Z+OB$. The PWM 42 modulates the pulse width of $-Z+OB$ received from the adder 38 to generate a square-wave signal Sr. The low-pass filter 43 extracts low-frequency components from the square-wave signal Sr supplied by the PWM 22 to generate the AGC signal SAG having a predetermined control voltage. Consequently, the gain of a loop formed by the tuner 30, the level detector LD, and the AGC signal generator SG is adjusted.

[0014]   The level converter LC is briefly described below. The level converter LC is provided to normalize the value of the integrated signal Z outputted from the integrator 22 before processed by the PWM 42 for correct gain control. Therefore, the inverse coefficient provider 24 provides the inverse coefficient, that is, a predetermined negative value, to the multiplier 23 for inverting the polarity of the integrated signal Z. The compensation coefficient provider 39 provides, for the sake of convenience of the processing in the PWM 42, the compensation

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coefficient *OB* having a predetermined value for compensating the inverted integrated signal Z ($-Z$) so that it takes a positive value or 0.

[0015]   The value of the compensation coefficient *OB* is determined based on the inverse coefficient provided by the inverse coefficient provider 24 and the number of output bits of the integrator 22. Now, consider the case where the inverse coefficient is -1, and the number of output bits of the integrator 22 is 12. In this case, the integrated signal Z takes a value in the range of -2048 to $+2047$. If the compensation coefficient *OB* is set to 12 bits (*OB* = 2048), which is the number of output bits of the integrator 22, the value of $-Z+OB$ outputted from the adder 38 falls within the range of 0 to $+4095$.

[0016]   If the error signal SE indicates 0, the value of $-Z+OB$ outputted from the adder 38 falls within the range of $+2048$ (*OB*). If the error signal *SE* has a negative value, $-Z+OB$ falls within the range of 0 to $+2047$. As such, correct gain control can be achieved according to the average level of the digital broadcast wave *Srf*.

[0017]   In other words, when a predetermined time has passed and the outputs from the integrator 22 become converged, the signal indicating any one of the following three values is supplied to the PWM 42, where the number of output bits of the integrator 22 is 12.

[0018]   Firstly, the output from the integrator 22 has a

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positive value if the average level of the digital broadcast wave *RF* is higher than the reference value *R* set in the reference value provider 17. Therefore, the PWM 42 receives a value of less than 2048.

[0019] Secondly, the PWM 42 receives a value of 2048 if the average level of the digital broadcast wave *RF* is equal to the reference value *R*.

[0020] Thirdly, the PWM 42 receives a value of equal to or larger than 2049 if the average level of the digital broadcast wave *RF* is lower than the reference value *R*.

[0021] Shown in FIG. 17 are waveforms of the square-wave signal *Sr*. In the PWM 42, the pulse width of the square-wave signal Sr is changed according to the received *−Z+OB*. For example, if *−Z+OB* is 4095, the square-wave signal *Sr* constant at 1 is outputted, as represented by a waveform *W1*. If *−Z+OB* is 2048, the square-wave signal *Sr* alternately indicating 0 and 1 is outputted, as shown in FIG. 17, as represented by a waveform *W2*. If *−Z+OB* is 0, the square-wave signal *Sr* constant at 0 is outputted, as represented by a waveform *W3*.

[0022] Then, the square-wave signal *Sr* is converted by the low-pass filter 43 into the AGC signal *SAG* having a DC voltage. Then, the AGC signal *SAG* is outputted to the RF gain control point setter 40.

[0023] The RF gain control point setter 40 generates the RF AGC signal *SAGr* for attenuating the gain of the RF automatic gain

controller 2 when the value of the AGC signal SAG becomes lower than a predetermined value. The RF gain control point setter 40 also generates the IF AGC signal $SAGi$ for always varying the gain of the IF automatic gain controller 5.

5   [0024]   FIGS. 15 and 16 schematically illustrate processes on various signals generated in the level detector LD and the AGC signal generator SG in an arbitrary control cycle t. Throughout this specification, the control cycle is represented as t. That is, a control cycle previous to the control cycle t is represented

10   as t with a natural number added thereto, and the one next thereto as t with a natural number subtracted therefrom. As such, the control cycle t is also a parameter indicating a relative time. Furthermore, for the sake of convenience, the control cycle t may be simply referred to as "t", and also each signal and parameter

15   may be referred to as its reference character.

[0025]   As shown in FIG. 15, the subtractor 12 of the level detector LD subtracts the averaged signal $Y(t+1)/2^n$ supplied by the bit shifter 15 from $SMD(t)$ supplied by the A/D converter 6 to generate $SMD(t)-Y(t+1)/2^n$.

20   [0026]   The adder 13 of the integrator 100 adds $SMD(t)-Y(t+1)/2^n$ supplied by the subtractor 12 to the integrated signal $Y(t+1)$ supplied by the delay unit 14 to generate $SMD(t)-Y(t+1)/2^n+Y(t+1)$ $= SMD(t)+Y(t+1)(1-2^{-n})$.

[0027]   The delay unit 14 delays $SMD(t)+Y(t+1)(1-2^{-n})$ outputted

25   from the adder 13 by one control cycle t to generate an integrated

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signal $Y(t+1)$.

[0028]   The bit shifter 15 shifts the integrated signal $Y(t+1)$ by the predetermined number of shift bits n to generate an averaged signal $Y(t+1)/2^n$. This averaged signal $Y(t+1)/2^n$ is equivalent to the average of 2^n data values of the modulated digital signal SMD supplied to the level detector LD. In this sense, the number of shift bits n defines the number of data values required for finding the average value by the bit shifter 15. In other words, 2^n is the number of data values required for finding the average value of the modulated digital signal SMD supplied to the level detector LD, and the number of shift bits n is an averaging coefficient. Hereinafter, 2^n is referred to as the number of data values for averaging.

[0029]   Next, as shown in FIG. 16, the subtractor 16 of the AGC signal generator SG subtracts the reference value R provided by the reference value provider 17 from the level signal SL supplied by the level detector LD to generate the error signal $SE(t)$.

[0030]   The multiplier 18 multiplies $SE(t)$ supplied by the subtractor 16 by the constant G provided by the constant provider 19 to generate $G \cdot SE(t)$.

[0031]   The adder 20 of the integrator 22 adds $G \cdot SE(t)$ supplied by the multiplier 18 to the integrated signal $Z(t+1)$ outputted from the delay unit 21 to generate $G \cdot SE(t)+Z(t+1)$.

[0032]   The delay unit 21 delays $G \cdot SE(t)+Z(t+1)$ supplied by the adder 20 by one control cycle t to generate the integrated

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signal $Z(t+1)$.

[0033]   The multiplier 23 of the level converter LC multiplies the integrated signal $Z(t+1)$ received from the delay unit 21 by the inverse coefficient "-1" received from the inverse coefficient provider 24 to generate $-Z(t+1)$.

[0034]   The adder 38 adds $-Z(t+1)$ supplied by the multiplier 23 to the compensation coefficient OB provided by the compensation coefficient provider 39 to generate $-Z(t+1)+OB$.

[0035]   The PWM 42 modulates the pulse width of $-Z(t+1)+OB$ supplied by the level converter LC to generate a square-wave signal Sr.   The low-pass filter 23 extracts low-frequency components from the square-wave signal Sr supplied by the PWM 42 to generate the AGC signal SAG at a desired stable level.

[0036]   Shown in FIG. 18 are changes in the gain of the RF automatic gain controller 2 and the IF automatic gain controller 5 with respect to the digital broadcast wave RF.   In FIG. 18, the vertical axis VA represents attenuation (dB) from the maximum gain, and the lateral axis LRF represents the level of the digital broadcast wave RF.   A solid line LR represents gain attenuation of the RF automatic gain controller 2, while a dotted line LI represents that of the IF automatic gain controller 5.

[0037]   As is evident from FIG. 18, when the attenuation is 0, the maximum gain is observed for both of the RF and IF automatic gain controllers 2 and 5.   Between -78dBm and -5dBm, the gain is attenuated mainly by the RF automatic gain controller 2, but also

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slightly by the IF automatic gain controller 5. This is because

the ratio of the RF AGC signal to attenuation achieved by the RF

automatic gain controller 2 is larger than the ration of IF AGC

signal to attenuation achieved by the IF automatic gain controller

5   5.

[0038]   When the level of the digital broadcast wave *RF* is in

the ranges of 0dBM to -178dBm and over -5dBm, the gain is attenuated

only by the IF automatic gain controller 5.

[0039]   Under -78dBm, the RF automatic gain controller 2

10   generates the RF AGC signal *SAGr* to prevent attenuation in itself.

Over -5dBm, the RF automatic gain controller 2 can hardly

attenuate the gain, and the IF automatic gain controller 5

automatically controls the gain.

[0040]   The reason of such control is that the gain of the RF

15   and IF automatic gain controllers 2 and 5 has to be appropriately

adjusted according to the level of the digital broadcast wave *RF*.

More specifically, in a low electric field intensity where the

digital broadcast wave *RF* is under -78dBm, degradation of the C/N

(Carrier to Noise) ratio at the tuner 30 has to be prevented. In

20   that case, control is carried out so that the noise factor at the

tuner 30 becomes lower, that is, the gain of the RF automatic gain

controller 2 becomes maximum.

[0041]   As the level of the digital broadcast wave *RF* becomes

higher, the capabilities at the mixer 3 of suppressing

25   intermodulation-distortion interference and adjacent-channel

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interference have to be increased. Therefore, over -78dBm, the gain of the RF automatic gain controller 2 is mainly attenuated so that the level of the signal supplied to the mixer 3 does not become increased. Then, over -5dBm where the RF automatic gain

5   controller 2 can no longer control the gain, the IF automatic gain controller 5 is started in operation.

[0042]   Shown in FIG. 19 are changes in the gain of the RF automatic gain controller 2 and the IF automatic gain controller 5 with respect to the level of the digital broadcast wave *RF* in

10   an AGC apparatuses disclosed in Japanese Patent Gazettes Nos. 2699698 and 2778260. Also in FIG. 19, the vertical axis *VA* represents attenuation (dB) from the maximum gain, and the lateral axis *LRF* represents the level of the digital broadcast wave *RF*. A solid line *LR* represents gain attenuation of the RF automatic

15   gain controller 2, while a dotted line *LI* represents that of the IF automatic gain controller 5.

[0043]   In these automatic gain controllers, for increasing the capabilities   of   suppressing   intermodulation-distortion interference and adjacent-channel interference when the level of

20   the digital broadcast wave *RF* is -78dBm, the gain of the RF automatic gain controller (corresponding to a low-noise amplifier in the above Gazette No. 2699698 and a first gain control circuit in the above Gazette No. 2778260) is maximized, whiled the gain of the IF automatic gain controller is attenuated. Over -78dBm,

25   the gain of the IF automatic gain controller is made constant,

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while the gain of the RF automatic gain controller is attenuated. Consequently, the maximum attenuation is 65dB for the RF automatic gain controller, and 17dB for the IF automatic gain controller. Therefore, the amount of change in gain, that is, a dynamic range, of the receiver is 82dB.

[0044]   However, the receive level of the digital broadcast wave for ground-wave digital broadcast receivers to display on television is -85dBm to 5dBm, and the dynamic range is 90dB. Controlling the level of the RF input signal by both RF and IF automatic gain controllers requires some margin in dynamic range, and therefore the dynamic range has to be 100dB in reality. Also, for ensuring the dynamic range of 100dB, the maximum attenuation of the IF automatic gain controller may be controlled to 35dB, as shown in FIG. 20.

[0045]   In this case, however, when the level of the digital broadcast wave *RF* is under -60dBm, the gain of the RF automatic gain controller is maximized, while the gain of the IF automatic gain controller is attenuated. Over -60dBm, the former is attenuated, while the latter is made constant. Consequently, the attenuation of the RF automatic gain controller 2 at -50dBm is 13dB, thereby increasing the level of the signal supplied to the mixer 3. Therefore, when the level of the digital broadcast wave is at -50dBm, for example, the capability of suppressing intermodulation-distortion interference is significantly degraded and, in turn, the capability of suppressing

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adjacent-channel interference is also significantly degraded.

[0046] As stated above, in the conventional AGC apparatus *AGC* characterized by the changes in the gain of RF and IF automatic gain controller 2 and 5 as shown in FIG. 18, when the digital broadcast wave *RF* is in the range of -78dBm to 15dBm, the gain of the RF automatic gain controller 2 is attenuated. In that range, the gain of the IF automatic gain controller 5 is also attenuated, although slightly, by approximately 7dB (changed from 18dB to 25dB).

[0047] For example, the gain attenuation of the IF automatic gain controller 5 is 18dB when the level of the digital broadcast wave *RF* is at -78dBm, while 22dB at -50dBm. As a result, the attenuation is increased by 4dB. Therefore, the signal supplied to the mixer 3 is increased in level by 4dB at -50dBm, compared with the case where the gain attenuation of the IF automatic gain controller 5 does not change at all in the range of -78dBm to -5dBm. Such increase disadvantageously causes degradation by 4dB in the capability of suppressing intermodulation-distortion interference and, in turn, the capability of suppressing adjacent-channel interference.

[0048] In another example, the gain attenuation of the IF automatic gain controller 5 is 18dB when the level of the digital broadcast wave *RF* is at -78dBm, while 25dB at -5dBm. As a result, the attenuation is increased by 7dB. Therefore, the signal supplied to the mixer 3 is increased in level by 7dB at -5dBm,

compared with the case where the gain attenuation of the IF automatic gain controller 5 does not change at all in the range of -78dBm to -5dBm. Such increase disadvantageously causes degradation by 7dB in capability of suppressing intermodulation-distortion interference.

[0049]   Furthermore, in the above Gazettes, when ground-wave digital broadcasting is received, the stronger the capability of suppressing adjacent-channel interference is made, the narrower the dynamic range becomes. And, the wider the dynamic range is made, the weaker the capability of suppressing intermodulation-distortion interference becomes, resulting in significant degradation of the capability of suppressing the adjacent-channel interference.

SUMMARY OF THE INVENTION

[0050]   Therefore, an object of the present invention is to solve the above problems by providing an AGC apparatus that can achieve a wider dynamic range without impairment of the capabilities of suppressing intermodulation-distortion interference and adjacent-channel interference.

[0051]   The present invention has the following features to attain the object above.

[0052]   A first aspect of the present invention is directed to an automatic gain control apparatus that comprises an RF automatic gain controller for controlling gain of a radio frequency signal;

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a frequency converter for frequency-converting the radio frequency signal into an intermediate frequency signal; an IF automatic gain controller for controlling gain of the intermediate frequency signal; a level detector for detecting a signal level of the intermediate frequency signal with the gain controlled, and generating a level signal; and automatic gain control signal generator for generating, based on the level signal, an RF automatic gain control signal for controlling the RF automatic gain controller and an IF automatic gain control signal for controlling the IF automatic gain controller, to separately control the RF automatic gain controller and the IF automatic gain controller.

[0053]   As described above, in the first aspect, the RF and IF automatic gain controllers are separately controlled. Therefore, it is possible to improve the capabilities of suppressing adjacent-channel interference and intermodulation-distortion interference with a large dynamic range.

[0054]   According to a second aspect, in the first aspect, if the level signal indicates a level equal to or lower than a first predetermined level, the automatic gain control signal generator fixes the gain of the RF automatic gain controller to a maximum value, and changes the gain of the IF automatic gain controller, if the level signal indicates a level higher than the first predetermined level and equal to or lower than a second predetermined level, the automatic gain control signal generator

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fixes the gain of the IF automatic gain controller to the first predetermined value, and changes the gain of said RF automatic gain controller. If said level signal indicates a level higher than said second predetermined level, said automatic gain control

5   signal generator fixes the gain of said RF automatic gain controller to a second predetermined value, and changes the gain of the IF automatic gain controller.

[0055]   As described above, in the second aspect, the same effects as in the first aspect can be achieved with the dynamic

10   range more varied.

[0056]   According to a third aspect, in the first aspect, if the level signal indicates a level equal to or lower than a third predetermined level, the automatic gain control signal generator fixes the gain of the RF automatic gain controller to a maximum

15   value. If the level signal indicates a level higher than the third predetermined level and equal to or lower than a fourth predetermined level, the automatic gain control signal generator changes the gain of the IF automatic gain controller. If the level signal indicates a level higher than the fourth predetermined

20   level, the automatic gain control signal generator fixes the gain of the RF automatic gain controller to a third predetermined value. If the level signal indicates a level equal to or lower than a fifth predetermined level, the automatic gain control signal generator changes the gain of the IF automatic gain controller.

25   If the level signal indicates a level higher than the fifth

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predetermined level and equal to or lower than a sixth predetermined level, the automatic gain control signal generator fixes the gain of the IF automatic gain controller to a fourth predetermined value. If the level signal indicates a level higher

5   than the sixth predetermined level, the automatic gain control signal generator changes the gain of the IF automatic gain controller.

[0057]   As described above, in the third aspect, the same effects as in the second aspect can be achieved.

10   [0058]   According to a fourth aspect, in the third aspect, the automatic gain control apparatus further comprises a microcomputer for setting the first and second predetermined levels at which the gain of the RF automatic gain controller and the gain of the IF automatic gain controller is changed or fixed,

15   a parameter indicating a gradient of the radio frequency signal to the RF automatic gain control signal while the gain of the RF automatic gain controller is changed, and a parameter indicating a gradient of the radio frequency signal to the IF automatic gain control signal while the gain of the IF automatic gain controller

20   is changed.

[0059]   As described above, in the fourth aspect, the same effects as in the first to third aspect can be achieved with a smaller circuit in size.

[0060]   According to a fifth aspect, in the third aspect, the

25   automatic gain control apparatus further comprises a

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microcomputer for setting the third and fourth predetermined levels at which the gain of the RF automatic gain controller is changed or fixed according to the radio frequency signal, the fifth and sixth predetermined levels at which the gain of the IF automatic gain controller is changed or fixed according to the radio frequency signal, a parameter indicating a gradient of the radio frequency signal to the RF automatic gain control signal while the gain of the RF automatic gain controller is changed, and a parameter indicating a gradient of the radio frequency signal to the IF automatic gain control signal while the gain of the IF automatic gain controller is changed.

[0061] As described above, in the fifth aspect, in addition to the same effects as in the fourth aspect, influences of variations in quality of the tuner can be reduced.

[0062] These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0063] FIG. 1 is a block diagram depicting the structure of an automatic gain control (AGC) apparatus according to a first embodiment of the present invention;

FIG. 2 is a block diagram depicting the structure of a first level detector shown in FIG. 1;

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FIG. 3 is a block diagram depicting the structure of a automatic gain control (AGC) signal generator shown in FIG. 1;

FIG. 4 is a diagram showing an input-to-output characteristic of an RF/IF gain control signal generator shown in FIG. 1;

FIG. 5 is a diagram showing attenuation characteristics of an RF input signal level to an RF automatic gain controller and an IF automatic gain controller shown in FIG. 1;

FIG. 6 is a diagram showing an input-to-output characteristic of the RF/IF gain control signal generator in one example modification of the AGC apparatus shown in FIG. 1;

FIG. 7 is a diagram showing attenuation characteristics of an RF input signal level to an RF automatic gain controller and an IF automatic gain controller in the modification example of the AGC apparatus shown in FIG. 1;

FIG. 8 is a diagram showing attenuation characteristics of the RF input signal level to the RF automatic gain controller and the IF automatic gain controller in the example modification of the AGC apparatus shown in FIG. 1, when the attenuation of the RF automatic gain controller is relatively small due to variations in quality of a tuner;

FIG. 9 is a diagram showing attenuation characteristics of the RF input signal level to the RF automatic gain controller and the IF automatic gain controller, when the attenuation of the RF automatic gain controller is relatively small due to variations

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in quality of the tuner;

FIG. 10 is a block diagram showing the structure of an AGC apparatus according to a second embodiment of the present invention;

5   FIG. 11 is a block diagram showing the structure of an RF/IF gain control signal generator shown in FIG. 10;

FIG. 12 is a diagram showing one example modification of the AGC apparatus shown in FIG. 10;

FIG. 13 is a block diagram showing the structure of an 10   RF/IF gain control signal generator as shown in FIG. 12;

FIG. 14 is a block diagram showing the structure of a conventional AGC apparatus;

FIG. 15 is a block diagram showing the structure of a level detector shown in FIG. 14;

15   FIG. 16 is a block diagram showing an AGC signal generator shown in FIG. 14;

FIG. 17 is a block diagram showing PWM output waveforms in the AGC apparatus shown in FIG. 14;

FIG. 18 is a diagram showing attenuation 20   characteristics of an RF input signal level to an RF automatic gain controller and an IF automatic gain controller in the AGC apparatus shown in FIG. 14;

FIG. 19 is a diagram showing attenuation characteristics of an RF input signal level to an RF automatic 25   gain controller and an IF automatic gain controller in the AGC

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apparatuses disclosed in Japanese Patent Gazettes Nos. 2699698 and 2778260, when suppressing adjacent-channel interference is of primary concern; and

FIG. 20 is a diagram showing the attenuation characteristics as in FIG. 19, when widening the dynamic range is of primary concern.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0064]   With reference to FIGS. 1, 2, 3, 4, 5, 6, 7, 8, and 9, described below first is an automatic gain control (AGC) apparatus according to a first embodiment of the present invention. Then, with reference to FIGS.10, 11, 12, and 13, described is an AGC apparatus according to a second embodiment of the present invention.

[0065]   (First embodiment)

With reference to FIGS. 1 through 9, described below is the AGC apparatus of the first embodiment. Prior to that, the basic concept of the present invention is first described. In the present invention, an RF automatic gain controller and an IF automatic gain controller are separately controlled. With this control, the present AGC apparatus can improve the capabilities of suppressing intermodulation-distortion interference and adjacent-channel interference with a wide dynamic range.

[0066]   As shown in FIG. 1, the AGC apparatus *AGCa* includes a tuner 30, an A/D converter 6, a level detector *Lda*, and an automatic

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gain control signal generator (hereinafter, AGC signal generator) *SGa*. The tuner 30 frequency-converts and amplifies a digital broadcast wave *RF* received by an antenna to generate an analog signal *SMAa*. The tuner 30 includes an RF automatic gain controller 2, a mixer 3, an oscillator 4, and an IF automatic gain controller 5.

[0067]   In the tuner 30, the RF automatic gain controller 2 carries out automatic gain control and amplification on the digital broadcast wave *RF* to generate a digital broadcast wave *Srfa*. This is done based on an RF automatic gain control signal (hereinafter, RF AGC signal) *SAGra* supplied by the AGC signal generator *SGa*. The mixer 3 frequency-converts the digital broadcast wave *Srfa* to an intermediate frequency signal *Sifa*. This is done based on a reference frequency signal *SB* supplied by the oscillator 4. The IF automatic gain controller 5 carries out automatic gain control and amplification on the intermediate frequency signal *Sifa* to generate a modulated analog signal *SMAa*. This is done based on an IF automatic gain control signal (hereinafter, IF AGC signal) *SAGia* supplied by the RF gain control point setter 40.

[0068]   The A/D converter 6 converts the modulated analog signal *SMAa* from analog to digital to generate a modulated digital signal *SMDa*. The modulated digital signal *SMDa* is outputted to the following demodulation processing and also to the level detector *LDa*.

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[0069]   The level detector LDa detects the average level of the modulated digital signal $SMDa$, and generates a level signal SLa. This level signal indicates the level of the output from the IF automatic gain controller 5, that is, the average level of the modulated analog signal SMA.

[0070]   The AGC signal generator SGa generates, based on the level signal SLa, the IF AGC signal $SAGia$ and the RF AGC signal $SAGra$.

[0071]   Shown in FIG. 2 is the level detector LDa in detail. As with the conventional level detector LD structuring the AGC apparatus AGC already described by referring to FIG. 15, the level detector LDa includes a subtractor 12, an adder 14, a delay unit 14, and a bit shifter 15. Here, the number of shift bit n for the level detector LDa is equal to that for the level detector LD (in this example, $n = 12$).

[0072]   With reference to FIG. 3, the AGC signal generator SGa is described. The AGC signal generator SGa includes a subtractor 16, a reference value provider 17, a multiplier 18, a constant provider 19, an integrator 22, a level converter LC, an RF/IF gain control signal generator 25a, a PWM 42i, a PWM 42r, an LPF (low-pass filter) 43i, and an LPF (low-pass filter) 43r. The reference value provider 17 outputs a reference value R for controlling the digital broadcast wave $SMAa$ outputted from the tuner 30 to have a desired value. The constant provider 19 provides a constant G for determine the gain of a loop formed by the tuner 30, the

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level detector *LDa*, and the AGC signal generator *SGa*. The integrator 22 includes an adder 20 and a delay unit 21. The level converter *LC* includes a multiplier 23, an inverse coefficient provider 24, an adder 38, and a compensation coefficient provider 39.

[0073] The subtractor 16 finds an error between the level signal *SLa* provided by the level detector *LDa* and the reference value *R* provided by the reference value provider 17, and generates an error signal *SEa*. The multiplier 18 multiplies the error signal *SEa* found in the subtractor 16 by the constant *G* received from the constant provider 19, and outputs the multiplication result *G · SEa* to the integrator 22.

[0074] In the integrator 22, the delay unit 21 delays *G · SEa* received from the multiplier 18 by one control cycle *t*, and then the adder 19 adds it to the current output. As such, the integrator 21 integrates *G · SEa*. The integration result is outputted as an integrated signal *Za* to the adder 20 and the level converter *LC*.

[0075] In the level converter *LC*, the multiplier 23 multiplies the integrated signal *Za* by an inverse coefficient "−1" received from the inverse coefficient provider 24, thereby inverting the polarity of the integrated signal *Za* to generate *−Za*. The adder 38 adds the compensation coefficient *OB* supplied by the compensation coefficient provider 39 to *−Za* supplied by the multiplier 23 to generate *−Za+OB*.

25

[0076]   The RF/IF gain control signal generator 25a generates, based on $-Za+OB$ received from the adder 38, an IF level signal SLi and an RF level signal SLr. The PWM 42i modulates the pulse width of the IF level signal SLi supplied by the RF/IF gain control signal generator 25a, and generates a square-wave signal Sri. The LPF 43i extracts low-frequency components from the square-wave signal Sri supplied by the PWM 42i, and generates the IF AGC signal $SAGi$ having a predetermined voltage. The PWM 42r modulates the pulse width of the RF level signal SLr supplied by the RF/IF gain control signal generator 25a, and generates a square-wave signal Srr. The LPF 43r extracts low-frequency components from the square-wave signal Srr supplied by the PWM 42r, and generates the RF AGC signal $SAGr$ having a predetermined voltage.

[0077]   The level converter LC is briefly described below. The level converter LC is provided to normalize the value of the integrated signal Za outputted from the integrator 22 before processed by the RF/IF gain control signal generator 25 for correct gain control even if the value of integrated signal Za is larger than the reference value. Therefore, the inverse coefficient provider 24 provides the inverse coefficient, that is, a predetermined negative value, to the multiplier 23 for inverting the polarity of the integrated signal Za. The compensation coefficient provider 39 provides, for the sake of convenience of the RF/IF gain control signal generator 25, the compensation coefficient OB having a predetermined value for

compensating the inverted integrated signal Za ($-Za$) so that it takes a positive value or 0.

[0078]   The value of the compensation coefficient OB is determined based on the inverse coefficient provided by the inverse coefficient provider 24 and the number of output bits of the integrator 22. Now, consider the case where the inverse coefficient is -1, and the number of output bits of the integrator 22 is 12. In this case, the integrated signal Za takes a value in the range of -2048 to $+2047$. If the compensation coefficient OB is set to 12 bits ($OB = 2048$), which is the number of output bits of the integrator 22, the value of $-Za+OB$ outputted from the adder 38 falls within the range of 0 to $+4095$.

[0079]   If the output Za from the integrator 22 indicates 0, the value of $-Za+OB$ outputted from the adder 38 falls within the range of $+2048$ (OB). If the error signal SE has a negative value, $-Za+OB$ falls within the range of 0 to $+2047$. If the output Za is indicates a positive value, $-Za+OB$ falls within the range of $+2049$ to $+4095$. As such, correct gain control can be achieved according to the average level of the digital broadcast wave RF.

[0080]   In other words, when a predetermined time has passed and the outputs from the integrator 22 become converged, the signal indicating any one of the following three values is supplied to the RF/IF gain control signal generator 25 according to the average level of the digital broadcast wave RF, where the number of output bits of the integrator 22 is 12.

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[0081]   Firstly, the output from the integrator 22 has a positive value if the average level of the digital broadcast wave RF is higher than the reference value R set in the reference value provider 17.   Therefore, the RF/IF gain control signal generator 25a receives a value of less than 2048.

[0082]   Secondly, the RF/IF gain control signal generator 25a receives a value of 2048 if the average level of the digital broadcast wave RF is equal to the reference value R.

[0083]   Thirdly, the RF/IF gain control signal generator 25a receives a value of equal to or larger than 2049 if the average level of the digital broadcast wave RF is lower than the reference value R.

[0084]   Shown in FIG. 4 is a relation between the RF level signal SLr and the IF level signal SLi with respect to the signal (−$Za+OB$) supplied to the RF/IF gain control signal generator 25a. The vertical axis represents the level of the RF level signal SLr and the IF level signal SLi, while the lateral axis represents the value of integrated signal $Za+OB$ supplied to the RF/IF gain control signal generator 25a.   A solid line LR represents the RF level signal SLr, while a dotted line LI represents the IF level signal SLi.   X1 and X2 on the lateral axis indicate values of $Za+OB$ when the characteristic of the RF and IF level signal SLr change.

[0085]   In FIG. 4, the IF level signal SLi increases at a predetermined rate while the value of $Za+OB$ increases from 0 to X1.   That is, the dotted line LI extends having a predetermined

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gradient *aif*. Between X1 and X2, the level signal *SLi* has a constant value. Then, from X2 to 4095, the level signal *SLi* again increases having the predetermined gradient *aif*.

[0086]   On the other hand, the RF level signal *SLr* is constant at 0 and does not change while the value of *Za+OB* increases from 0 to X1. That is, the solid line *LR* extends having a gradient of 0. Between X1 and X2, the level signal *SLr* increases at a predetermined rate, and then reaches 4095 at X2. Then, from X2 to 4095, the level signal *SLr* is constant at 4095 without change.

[0087]   The characteristic of the RF level signal *SLr* typified by the solid line *LR* is represented by the following equations (1), (2), (3), (4), and (5), while the characteristic of the IF level signal *SLi* typified by the dotted line *LI* is represented by the following equations (6), (7), (8), (9), and (10). Note that, in the following equations, *y* corresponds to the vertical axis in FIG. 4, that is, the RF and IF level signals *SLr* and *SLi*. And, *x* corresponds to the lateral axis in FIG. 4, that is, the value of integrated signal *Za+OB* supplied to the RF/IF gain control signal generator 25*a*. In the following description as to FIG. 4, the value of the signal −*Za+OB* supplied to the RF/IF gain control signal generator 25*a* is simply referred to as "value *x*", and the values of the RF and IF level signals *SLr* and *SLi* are simply referred to as "value *y*", for convenience. Also note that "*brf*" in the following equations (2) and (12) and "*bif*" in the following equations (8) and (18) are constants.

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$$y = 0 \quad (X1 \geqq x) \qquad \ldots (1)$$

$$y = arf \cdot x + brf \qquad \ldots (2)$$

$$y = 4095 \quad (x > X2) \qquad \ldots (3)$$

$$arf = 4095/(X2 - X1) \qquad \ldots (4)$$

$$brf = -4095 \cdot X1/(X2 - X1) \qquad \ldots (5)$$

$$y = aif \cdot x \quad (X1 \geqq x) \qquad \ldots (6)$$

$$y = aif \cdot X1 \quad (X2 \geqq x > X1) \qquad \ldots (7)$$

$$y = aif \cdot x + bif \quad (x > X2) \qquad \ldots (8)$$

$$aif = 4095/(4095 + X1 - X2) \qquad \ldots (9)$$

$$bif = (X1 - X2)/(4095 + X1 - X2) \qquad \ldots (10)$$

[0088] Described next are changes in the RF and IF level signals *SLr* and *SLi* when the digital broadcast wave *RF* is gradually increased from a relatively low level. When the digital broadcast wave *RF* is at a minimum level, the value *x* supplied to the RF/IF gain control signal generator 25*a* takes a maximum value, that is, 4095, and the RF and IF level signals *SLr* and *SLi* both become maximum, that is, 4095. Then, as the input level of the digital broadcast wave *RF* gradually increases, the value *x* is gradually decreased

[0089] Where X2 < *x* ≦ 4095, the RF level signal *SLr* becomes constant at 4095 according to the above equation (3). The IF level signal *SLi* becomes gradually decreased from 4095 according to the above equation (8).

[0090] As the RF input signal is further increased to satisfy X1 < *x* ≦ X2, the IF level signal *SLi* becomes constant at $y = aif \cdot$

X1 according to the above equation (7) (here, according to the

above equation (9), $aif = 4095/(4095 + X1 - X2)$). Then, the RF

level signal SLr is gradually decreased from 4095 according to

the above equation (2).

5   **[0091]**   As the RF input signal $(-Za+OB)$ is further increased to

satisfy $0 < x \leqq X1$, the RF level signal SLr becomes constant at

0 according to the above equation (1). The IF level signal SLi

becomes gradually decreased from $y = aif \cdot x$ ($aif = 4095/(4095$

$+ X1 - X2)$) according to the above equation (6).

10   **[0092]**   Note that, as described above, the RF level signal SLr

is modulated in pulse width by the PWM $42r$, converted into a DC

voltage through the LPF $43r$, and then used as the RF AGC signal

$SAGr$ for controlling the RF automatic gain controller 2. Also

as described above, the IF level signal SLi is modulated in pulse

15   width by the PWM $42i$, converted into a DC voltage through the LPF

$43i$, and then used as the IF AGC signal $SAGi$ for controlling the

IF automatic gain controller 5.

[0093]   Shown in FIG. 5 are changes in gain of the RF automatic

gain controller 2 and the IF automatic gain controller 5 with

20   respect to the digital broadcast wave RF in the present AGC

apparatus. In FIG. 5, the vertical axis VA represents attenuation

(dB) from maximum gain, while the lateral axis LRF represents the

level of the digital broadcast wave RF. A solid line LR represents

the attenuation of the RF automatic gain controller 2, while a

25   dotted line Li represents the attenuation of the IF automatic gain

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controller 5.

[0094]   As is evident from the drawing, when the input level
(*LRF*) is -50dBm, the attenuation (*LR*) of the RF automatic gain
controller 2 is 29dB, which is 4dB higher that of the conventional
5   AGC apparatus *AGC* (25dB, refer to FIG. 18). This means that the
signal supplied to the mixer 3 is 4dB lower in level than that
of the conventional AGC apparatus *AGC*. That is, the AGC apparatus
of the present embodiment can advantageously improve, by 4dB, the
capability of suppressing adjacent-channel interference, which
10   is degraded at the mixer 3 by intermodulation-distortion
interference in the conventional AGC apparatus *AGC*.

[0095]   Moreover, in the present embodiment, when the input
level (*LRF*) is -10dBm, the attenuation (*LR*) of the RF automatic
gain controller 2 is 65dB, which is 6dB higher than that of the
15   conventional AGC apparatus *AGC* (59dB, refer to FIG. 18). This
means that the signal supplied to the mixer 3 is 6dB lower in level
than that of the conventional AGC apparatus *AGC*. That is, the
AGC apparatus of the present embodiment can advantageously
improve   the   capability   of   suppressing   intermodulation-
20   distortion interference that occurs in the mixer 3 at a high
electric field.

[0096]   Next, with reference to FIGS. 6, 7, 8, and 9, one example
modification of the above AGC apparatus *AGCa* is described. An
AGC apparatus *AGCa'* according to the present example modification
25   is similar in structure to the AGC apparatus *AGCa* except that the

RF/IF gain control signal generator 25*a* is replaced by an RF/IF gain control signal generator 25*a'*. Therefore, the structure of the AGC apparatus *AGCa'* is not described and illustrated in any drawing herein. However, the operation of the RF/IF gain control

5   signal generator 25*a'* is slightly different from that of RF/IF gain control signal generator 25*a*, and therefore is now described below.

[0097]   With reference to FIG. 6, the operation of the RF/IF gain control signal generator 25*a'* is described. In FIG. 6, as

10   with FIG. 4 referred to the above, a relation between the RF level signal *SLr* and the IF level signal *SLi* with respect to the signal $(-Za+OB)$ supplied to the RF/IF gain control signal generator 25*a'*. The vertical axis represents the level of the RF level signal *SLr* and the IF level signal *SLi*, while the lateral axis represents

15   the value of integrated signal $Za+OB$ supplied to the RF/IF gain control signal generator 25*a*. A solid line *LR* represents the RF level signal *SLr*, while a dotted line *LI* represents the IF level signal *SLi*.

[0098]   As is evident from the drawing, in the RF/IF gain control

20   signal generator 25*a'*, the value *x*, which is an input value of the RF/IF gain control signal generator 25*a'*, is set to satisfy $X3 < x \leq X4$ in a range where the RF level signal *SLr* is changed, while $X4 < x \leq 4095$ and $x \leq X3$ in a range where the RF level signal *SLr* is kept constant. Also, the value *x*, is set to satisfy X4

25   $< x \leq 4095$ and $x \leq X5$ in a range where the IF level signal *SLi*

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is changed, while X5 < x ≤ X6 in a range where the IF level signal *SLi* is kept constant.

[0099]   As to the relation between the RF and IF level signals *SLr* and *SLi* with respect to the input in the above RF/IF gain control signal generator 25*a*', when the RF level signal *SLr* is constant (in the drawing, X4 < x ≤ 4095 and x ≤ X3), the IF level signal *SLi* is changed. When the IF level signal *SLi* is constant (in the drawing, X5 < x < X6), the RF level signal *SLr* is changed. Where X3 < x ≤ X5 and X6 < x ≤ X4, the RF and IF level signals *SLr* and *SLi* are changed both. Therefore, the RF/IF gain control signal generator 25*a* controls them interrelated to each other while the RF/IF gain control signal generator 25*a*' can separately control the RF and IF level signals *SLr* and *SLi*.

[0100]   In the RF/IF gain control signal generator 25*a*', the characteristic of the RF level signal *SLr* typified by the solid line *LR* is represented by the following equations (11), (12), (13), (14), and (15), while the characteristic of the IF level signal *SLi* typified by the dotted line *LI* is represented by the following equations (16), (17), (18), (19), and (20).

$$y = 0 \ (X3 \geqq x) \qquad \qquad \ldots (11)$$

$$y = aif \cdot x + brf \ (X4 \geqq x > X3) \qquad \ldots (12)$$

$$y = 4095 \ (x > X4) \qquad \qquad \ldots (13)$$

$$arf = 4095/(X4 - X3) \qquad \qquad \ldots (14)$$

$$brf = -4095 \cdot X3/(X4 - X3) \qquad \ldots (15)$$

$$y = aif \cdot x \ (X5 \geqq x) \qquad \qquad \ldots (16)$$

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$$y = aif \cdot X5 \quad (X6 \geqq x > X5) \qquad \ldots(17)$$

$$y = aif \cdot x + bif \quad (x > X6) \qquad \ldots(18)$$

$$aif = 4095/(4095 + X5 - X6) \qquad \ldots(19)$$

$$bif = (X5 - X6)/(4095 + X5 - X6) \qquad \ldots(20)$$

[0101] With reference to FIG. 6, described next are the states of the RF and IF level signal SLr and SLi in the present example modification when the digital broadcast wave RF is gradually increased from a relatively low level. Also in FIG. 6, as with FIG. 4, the vertical axis represents the level of the RF level signal SLr and the IF level signal SLi, while the lateral axis represents the value of integrated signal $Za+OB$ supplied to the RF/IF gain control signal generator $25a'$. A solid line LR represents the RF level signal SLr, while a dotted line LI represents the IF level signal SLi. X3 and X4 on the lateral axis indicate values of $Za+OB$ when the characteristic of the RF level signal SLr changes, while X5 and X6 thereon indicate values of $Za+OB$ when the characteristic of the IF level signal SLi changes.

[0102] When the digital broadcast wave RF is at a minimum level, the value x supplied to the RF/IF gain control signal generator $25a'$ takes a maximum value, that is, 4095, and the RF and IF level signals SLr and SLi both become maximum, that is, 4095. Then, as the input level of the digital broadcast wave RF gradually increases, the value x supplied to the RF/IF gain control signal generator $25a'$ is gradually decreased. Where $X4 < x \leqq 4095$, the RF level signal SLr becomes constant at 4095 according to the above

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equation (13). The IF level signal SLi becomes gradually decreased from 4095 according to the above equation (18).

[0103]   As the digital broadcast wave RF is further increased to satisfy $X6 < x \leq X4$, the RF level signal SLr becomes gradually

5   decreased from 4095 according to the above equation (12), and the IF level signal SLi also becomes gradually decreased according to the above equation (18). In short, the RF and IF level signals SLr and SLi are both changed in a range $X6 < x \leq X4$. As the digital broadcast wave RF is further increased to satisfy $X5 < x \leq X6$,

10   the RF level signal SLr is further gradually decreased according to the above equation (12). The IF level signal SLi becomes constant at $y = aif \cdot X5$ (here, $aif = 4095/(4095 + X5 - X6)$) according to the above equation (17).

[0104]   As the digital broadcast wave RF is still further

15   increased to satisfy $X3 < x \leq X5$, the RF level signal SLr is further gradually decreased according to the above equation (12), and the IF level signal SLi also becomes gradually decreased from $y = aif \cdot$ X5 (here, $aif = 4095/(4095 + X5 - X6)$) according to the above equation (16). In short, the RF and IF level signals SLr and SLi

20   are both changed in a range $X3 < x \leq X5$. As the digital broadcast wave RF is still further increased to satisfy $0 < x \leq X3$, the RF level signal SLr becomes constant at 0 according to the above equation (11), and the IF level signal SLi is further gradually decreased according to the above equation (16).

25   [0105]   With reference to FIG. 7, described is attenuation

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characteristics of the RF automatic gain controller 2 and the IF automatic gain controller 5 with respect to the input level of the digital broadcast wave RF in the present invention if X4 = X6.

5   **[0106]**   Due to variations in quality of the tuner 30, the (gain) attenuation of the RF automatic gain controller 2 is varied according to the tuner 30, in some cases. For example, in the conventional AGC apparatus AGC, the maximum attenuation of the RF automatic gain controller 2 is 51dB as shown in FIG. 9, and

10   65dB as shown in FIG. 19. Also in the AGC apparatus $AGCa$ of the present embodiment, the maximum attenuation thereof is 51dB as shown in FIG. 9, and 65dB as shown in FIG. 5.

[0107]   In the above AGC apparatus $AGCa$, if the attenuation of the RF automatic gain controller 2 in the tuner 30 is varied, the

15   RF/IF gain control signal generator 25a has to carry out control in accordance with the minimum attenuation of the RF automatic gain controller 2, as shown in FIG. 8. That is, even if the RF automatic gain controller 2 is capable of carrying out attenuation up to 65dB as shown in FIG. 5, the values of X1 and X2 in FIG.

20   4 have to be determined in accordance with the minimum attenuation of 51dB as shown in FIG. 9.

[0108]   Consider a case where the values of X1 and X2 shown in FIG. 4 are determined based on the assumption that the attenuation of the RF automatic gain controller 2 is 65dB as shown in FIG.

25   5 and does not varied. In this case, in the range X1 < x $\leqq$ X1′

where the RF level signal *SLr* is changed as shown in FIG 4, the actual attenuation of the automatic gain controller 2 of the tuner 30 varied in quality is slightly over 51dB, but then plateaued at 51dB.

[0109]   That is, $X1 < x \leqq X1'$ shown in FIG. 4, there exists a problem that no change is observed in both of the attenuations of the RF automatic gain controller 2 and the IF automatic gain controller 5. Furthermore, when the values of X1 and X2 shown in FIG. 4 are determined, based on the assumption that the attenuation of the RF automatic gain controller 2 is 65dB as shown in FIG. 5 and does not vary, the tuner 30 whose attenuation of the RF automatic gain controller 2 is over 65dB has to be selected, leading to an increase in cost of the tuner 30.

[0110]   In the example embodiment as shown in FIG. 6, if the RF/IF gain control signal generator 25a separately controls the RF level signal *SLr* and IF level signal *SLi*, such problems as described above in the first embodiment can be solved. More specifically, as shown in FIG. 7, the RF and IF automatic gain controller 2 and 5 both operate in the range of −25dBm to −10dBm of the digital broadcast wave *RF*. With such operation, the attenuation of the RF automatic controller 2 is 29dB at −50dBm of the digital broadcast wave *RF*. This attenuation is 4dB larger than that in the conventional AGC apparatus *AGC* shown in FIG. 14, that is, 25dB. That is, in the present invention, the level of the signal supplied to the mixer 3 is 4dB lower than that of the

conventional apparatus, thereby improving, by 4dB, the capability of suppressing adjacent-channel interference at the mixer 3 due to intermodulation-distortion interference.

[0111]   Further, the attenuation of the RF automatic gain controller 2 at -10dBm of the digital broadcast wave *RF* is 59dB, as shown in FIG. 18, in the conventional example shown in FIG. 14, while 62dB in the present embodiment. That is, the level of the signal supplied to the mixer 3 is 3dB lower than that of the conventional apparatus, thereby improving, by 3dB, the capability of suppressing the intermodulation-distortion interference degraded at the mixer.

[0112]   (Second embodiment)

With reference to FIGS. 10 and 11, described below is the AGC apparatus of the second embodiment of the present invention. Prior to that, the basic concept of the AGC apparatus according to the second embodiment is first described. The characteristics of the AGC apparatus *AGCa* according to the first embodiment shown in FIG. 4 can be originally achieved if the parameters X1 and X2 in the above equations (1), (2), (3), (4), (5), (6), (7), (8), (9), and (10) are known. However, in addition to these parameters X1 and X2, the gradients *arf* and *aif*, and points of intersection of the RF and IF level signals and the y axis *brf* and *bif* are required. Therefore, it is obvious from the equations (4), (5), (9), and (10) that dividers are required.

[0113]   As long as these parameters X1, X2, *arf*, and *aif* are

known, the characteristics shown in FIG. 4 can be achieved without using such dividers. Therefore, if any parameter setting means such as a microcomputer that can provide and set these parameters is added, the desired gain characteristics can be realized without

5   requiring dividers.

[0114]   An AGC apparatus *AGCb* according to the present embodiment is similar in structure to the AGC apparatus *AGCa*, except that an AGC signal generator *SGb* is provided in place of the AGC signal generator *SGa*, and a microcomputer is newly added.

10   The AGC signal generator *SGb* is similar in structure to the AGC signal generator *SGa*, except that an RF/IF gain control signal generator 25*b* is provided in place of the RF/IF gain control signal generator 25*a*. A microcomputer 37 is provided as means for providing and setting the above stated parameters X1, X2, *arf*,

15   and *aif* to the AGC signal generator *SGb*. Therefore, the structure and operation similar to that of the AGC apparatus *AGCa* are not described herein, and only the RF/IF gain control signal generator 25*b* unique to the present embodiment is described herein.

[0115]   With reference to FIG. 11, the RF/IF gain control signal

20   generator 25*b* is described. The RF/IF gain control signal generator 25*b* mainly includes an RF level signal generator *Ur* for generating an RF level signal *SLr* and an IF level signal generator *Ui* for generating an IF level signal *SLi*. Such signal generation in both of the generators are based on the input from the level

25   converter *LC*.

[0116]   The RF level signal generator Ur includes a subtractor 47, a comparator 48, a 0-value provider 49, a switch 50, a multiplier 51, and a clipping circuit 52. The subtractor 47 is connected to the adder 38 of the level converter LC and to the microcomputer 37. The subtractor 47 subtracts X1 supplied by the microcomputer 37 from the $-Za+OB$ supplied by the level converter LC, and generates $-Za+OB-$X1.

[0117]   From a value x of $-Za+OB$ supplied to the RF/IF gain control signal generator 25b, X1 is subtracted by the subtractor 47, and $-Za+OB-$X1 is generated. The comparator 48 determines whether the value (level) of $-Za+OB-$X1 outputted from the subtractor 47 is equal to or smaller than 0, and generates a first level decision signal $Ssw1$. The switch 50 is connected to an output port of the 0-value provider 49, an output port of the subtractor 47, and an output port of the comparator 48. The switch 50 selects, based on the first level decision signal $Ssw1$ outputted from the comparator 48, either one of the output ports of the subtractor 47 and the 0-value provider 49, and then connects the selected one to an input port of the multiplier 51.

[0118]   As a result, the multiplier 51 receives either one of $-Za+OB-$X1 supplied by the subtractor 47 and a value of 0 provided by the 0-value provider 49. In more detail, if the output of the subtractor 47 is equal to or smaller than 0, the switch 50 outputs the value of 0, and otherwise, the switch 50 outputs the same value outputted from the subtractor 47. The output value from the

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switch 50 is multiplied by *arf* in the multiplexer 51. If the multiplication result is larger than 4095, the result (the output value from the multiplier 51) is clipped, and a value of 4095 is outputted as the RF level signal *SLrb*.

[0119]   As to the above equation (1), when $x \leqq$ X1, the value of 0 is outputted from the multiplier 51, goes through the multiplier 51 and the clipping circuit 52, and the resultant RF level signal *SLrb* becomes 0. As to the above equations (2), (3), (4), and (5), when X1 < $x \leqq$ X2, the output value x-X1 from the subtractor 47 is outputted from the switch 50, and *arf* · (x-X1) is outputted from the multiplier 51. From the clipping circuit 52, *arf* · (x-X1), that is, *arf* · x + *brf* = *arf* · (x-X1) in the above (1), (2), (3), (4), and (5), is outputted. When X2 $\leqq$ x, the output value from the subtractor 47 is outputted from the switch 50, *arf* · (x-X1) is outputted from the multiplier 51, and a value obtained by clipping *arf* · (x-X1), that is, 4095, is outputted from the clipping circuit 52.

[0120]   The IF level signal generator *Ui* includes a subtractor 53, a comparator 54, (in FIG. 11, denoted as "> X2"), a comparator 55 (in FIG. 11, denoted as "> X1"), an inverter 56, a multiplier 57, a multiplier 58, an adder 59, a switch 60, a switch 61, an AND circuit 62, and a switch 63.

[0121]   From the input value x of the RF/IF gain control signal generator 25*b*, X2 is subtracted by the subtractor 53, and − *Za*+*OB*−X2 is generated. The comparator 54 determines whether the

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value (level) of −*Za+OB*−X2 is larger than X2, and generates a second level decision signal *Ssw2*. The switch 63 is connected to an output port of the adder 38, an output port of the subtractor 53, and an output port of the comparator 54. The switch 63 selects, based on the second level decision signal *Ssw2* outputted from the comparator 54, either one of the output ports of the adder 38 and the subtractor 53, and then connects the selected one to an input port of the multiplier 57.

[0122]   That is, if the value x (−*Za+OB*) supplied to the RF/IF gain control signal generator 25*b* is larger than X2, the switch 63 outputs the output value *x*−X2 (−*Za+OB*−X2) from the subtractor 53. If the value *x* is equal to or smaller than X2, the switch 63 outputs, to the multiplier 57, the input value x (−*Za+OB*) to the RF/IF gain control signal generator 25*b*. The multiplier 57 multiplies the output value x (−*Za+OB* or −*Za+OB*−X2) by *aif* from the microcomputer 37 to generate (−*Za+OB*) · *aif* or (−*Za+OB*−X2) · *aif*.

[0123]   The multiplier 58 multiplies X1 by *aif*, both supplied by the microcomputer 37 to generate *aif* · X1. The adder 59 adds the (−*Za+OB*) · *aif* or (−*Za+OB*−X2) · *aif* supplied by the multiplier 57 to *aif* · X1 supplied by the multiplier 58 to generate (−*Za+OB*+X1) · *aif* or (−*Za+OB*−X2+X1) · *aif*.

[0124]   The switch 60 is connected to an output port of the multiplier 57, an output port of the adder 59, and the output port of the comparator 54, and also to an input port of the switch 61.

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The switch 60 outputs to the input port of the switch 61, based on the second level decision signal $Ssw2$ supplied by the comparator 54, either one of $(-Za+OB+X1) \cdot aif$ and $(-Za+OB-X2+X1) \cdot aif$ supplied by the adder 59 or either one of $(-Za+OB) \cdot aif$ or $(-Za+OB-X2) \cdot aif$ supplied by the multiplier 57.

[0125]   That is, if the value x $(-Za+OB)$ supplied to the RF/IF gain control signal generator 25b is larger than X2, the switch 60 outputs $(-Za+OB-X2+X1) \cdot aif$. If the value x is equal to or smaller than X2, the switch 60 outputs $(-Za+OB) \cdot aif$.

[0126]   Furthermore, the comparator 55 determines whether the value x $(-Za+OB)$ outputted from the adder 38 is larger than X1, and generates a fourth level decision signal $Ssw4$ to the AND circuit 62. The inverter 56 inverts the second level decision signal $Ssw2$ into a third level decision signal $Ssw3$, and outputs it to the AND circuit 62.

[0127]   When the value x $(-Za+OB)$ outputted from the adder 38 is larger than X1, the fourth level decision signal $Ssw4 = 1$. When $x \leqq X2$, $Ssw4 = 0$. When $x \leqq X2$, the second level decision signal $Ssw2 = 0$, and the third level decision signal $Ssw3 = 1$. When $x > X2$, the second level decision signal $Ssw2 = 1$, and the third level decision signal $Ssw3 = 0$. That is, if $X1 < x \leqq X2$, the output from the AND circuit 62, that is, a fifth level decision signal $Ssw5$ becomes 1, and otherwise, becomes 0.

[0128]   The switch 61 is connected to the output port of the multiplier 58, an output port of the switch 60, and an output port

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of the AND circuit 62. The switch 61 outputs, based on the fifth level decision signal $Ssw5$ outputted from the AND circuit 62, $aif \cdot X1$ or either one of $(-Za+OB) \cdot aif$ and $(-Za+OB-X2+X1) \cdot aif$ outputted from the switch 60, as the IF level signal $SLib$, to the
5 PWM 42i.

[0129] That is, when the value x $(-Za+OB)$ supplied to the RF/IF gain control signal generator 25b satisfies $X1 < x \leq X2$, the switch 61 outputs $aif \cdot X1$ outputted to the multiplier 58 as the IF level signal $SLib$. When $x \leq X1$ or $X2 < x$, the switch 61 outputs as the
10 IF level signal $SLib$ either one of $(-Za+OB) \cdot aif$ and $(-Za+OB-X2+X1) \cdot aif$ outputted from the switch 60.

[0130] In other words, in the equations (5), (6), (7), (8), and (9), when $x \leq X1$, the switch 63 outputs the input value x $(-Za+OB)$ itself. Then, the multiplier 57 outputs $aif \cdot (-Za+OB)$.
15 After going though the switches 60 and 61, the IF level signal $SLib$ becomes $aif \cdot x$.

[0131] In the equations (1), (2), (3), (4), and (5), when $x > X2$, the switch 63 outputs the output value $-Za+OB-X2$ from the subtractor 53. Then, the multiplier 57 outputs $aif \cdot (-Za+OB-$
20 $X2)$, and then the adder 59 outputs $aif \cdot (-Za+OB-X2+X1)$. After going though the switches 60 and 61, the IF level signal $SLib$ becomes $aif \cdot (-Za+OB-X2+X1)$.

[0132] As described in the foregoing, the AGC apparatus $AGCb$ is so structured as follows: The values of X1 and X2 are
25 determined in advance. Based on X1, X2, and also the equations

45

(4) and (9), *arf* and *aif* are derived. These parameter X1, X2, *arf*, and *aif* are then provided from the microcomputer 37 through an IC bus to the RF/IF gain control signal generator 25*b* in the AGC signal generator *SGb*. Consequently, no divider is required

5   for structuring the RF/IF gain control signal generator 25*b*, thereby reducing the circuit size.

[0133]   With reference to FIGS. 12 and 13, an example modification of the AGC apparatus *AGCb* according to the above second embodiment is described. As with the AGC apparatus *AGCb*,

10   an AGC apparatus of the example modification achieves the characteristics shown in FIG. 6 without using dividers. That is, the characteristics of the AGC apparatus *AGCa* shown in FIG. 6 can be realized as long as the parameters X3 and X4 in the equations (11), (12), (13), (14), and (15) and the parameters X5 and X6 in

15   the equations (16), (17), (18), (19), and (20) are known.

[0134]   However, in addition to these parameters X3, X4, X5, and X6, required are the gradients *arf* and *aif*, and points of intersection of the RF and IF level signals and the y axis *brf* and *bif* in the equations (12), (14), (15), (16), (17), (18), (19),

20   and (20). Therefore, it is obvious from the equations (14), (15), (19), and (20) that dividers are required. As long as the parameters X3, and *arf* are known, the characteristic of the RF/IF gain control signal generator input to the RF level signal can be obtained. Also, as long as the parameters X5, X6, and *aif* are

25   known, the characteristic of the RF/IF gain control signal

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generator input to the IF level signal can be obtained. Therefore, if any parameter setting means such as a microcomputer that can provide and set these parameters is added, the desired gain characteristics can be realized without requiring dividers.

5   **[0135]**   Illustrated in FIG. 13 is the processing in the components of an RF/IF gain control signal generator 25*b′* structured in the above manner, and the operation of these components is briefly described below. An AGC apparatus *AGCb′* according to the example embodiment is similar in structure and

10   operation to the AGC apparatus *AGCb*, except that the parameters X3, X5, and X6 are set by the microcomputer. However, the subtractor 47 of the AGC apparatus *AGCb′* is provided with X3 instead of X1, the subtractor 53 is provided with X6 instead of X2, and the multiplier 58 is provided with X5 instead of X1. As

15   a result, a comparator 54*c* is replaced by the comparator 54, and a comparator 55*c* is by the comparator 55. Note that, when the value x (−*Za*+*OB*) supplied by the adder 38 is larger than X5, the fourth level decision signal *Ssw4* = 1. When $x \leqq$ X5, *Ssw4* = 0. When $x \leqq$ X6, *Ssw2* = 0, and *Ssw3* = 1. When $x >$ X6, *Ssw2* = 1, and

20   *Ssw3* = 1. When X5 < x or $x \leqq$ X6, the fifth level decision signal *Ssw5* from the AND circuit 62 becomes 1. When X6< x or $x \leqq$ X5, *Ssw5* = 0.

[0136]   As with the RF/IF gain control signal generator 25*b*, in the RF/IF gain control signal generator 25*b′*, the multiplier

25   35, the subtractor 53, and the multiplier 58 *find arf* and *aif* based

on the X3, X5, and X6 provided by the microcomputer 37, by using

the equations (14) and (19). Then, X3, X5, and X6 provided through

the IC bus by microcomputer 37 and the found *arf* and *aif* are

transferred to the RF/IF gain control signal generator 25*b*.

5 Consequently, no divider is required for structuring the RF/IF

gain control signal generator 25*b*, thereby reducing the circuit

size.

[0137]   As described in the foregoing, in the present invention,

if the gain of the RF automatic gain controller is attenuated,

10 the gain of the IF automatic gain controller is made constant,

and vice versa. Therefore, the capabilities of suppressing

adjacent-channel interference and intermodulation-distortion

interference can be improved in consideration of variations in

quality of the tuner. Moreover, the parameters required for the

15 RF/IF gain control signal generator that determine the operation

of the RF and IF automatic gain controller are set by the

microcomputer. Thus, the circuit size can be reduced.

[0138]   While the invention has been described in detail, the

foregoing description is in all aspects illustrative and not

20 restrictive. It is understood that numerous other modifications

and variations can be devised without departing from the scope

of the invention.